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(54) **ON-DEMAND HEAT PUMP WATER HEATER**

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F24D 19/10 (2006.01)
F24H 4/06 (2006.01)

(52) **U.S. Cl.**
CPC ***F24H 4/04*** (2013.01); ***F24D 19/1015*** (2013.01); *F24H 4/06* (2013.01)

(58) **Field of Classification Search**
CPC F24H 4/04; F24H 4/06; F24D 19/1015
See application file for complete search history.

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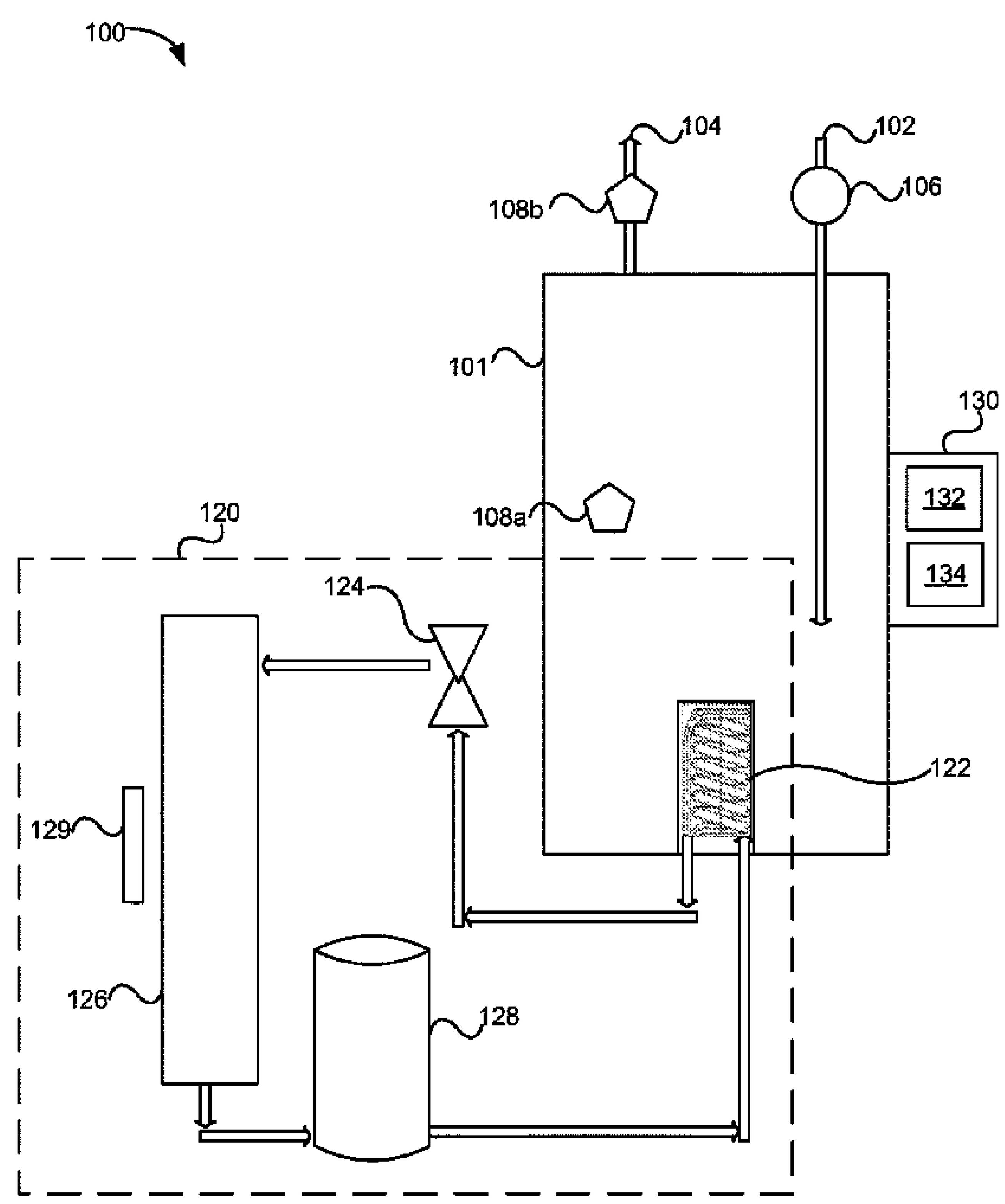
(57) **ABSTRACT**

The disclosed technology includes an on-demand water heater which uses a heat pump to heat the fluid. The on-demand heat pump water heater can have a low fluid capacity heating chamber which has an inlet and an outlet, a heat pump for heating the fluid, and a controller to control the heat pump and maintain the temperature of the fluid at a predetermined temperature. The on-demand heat pump water heater can include one or more temperature sensors, flow sensors, fluid mixing valves, or supplemental heat sources.

16 Claims, 4 Drawing Sheets



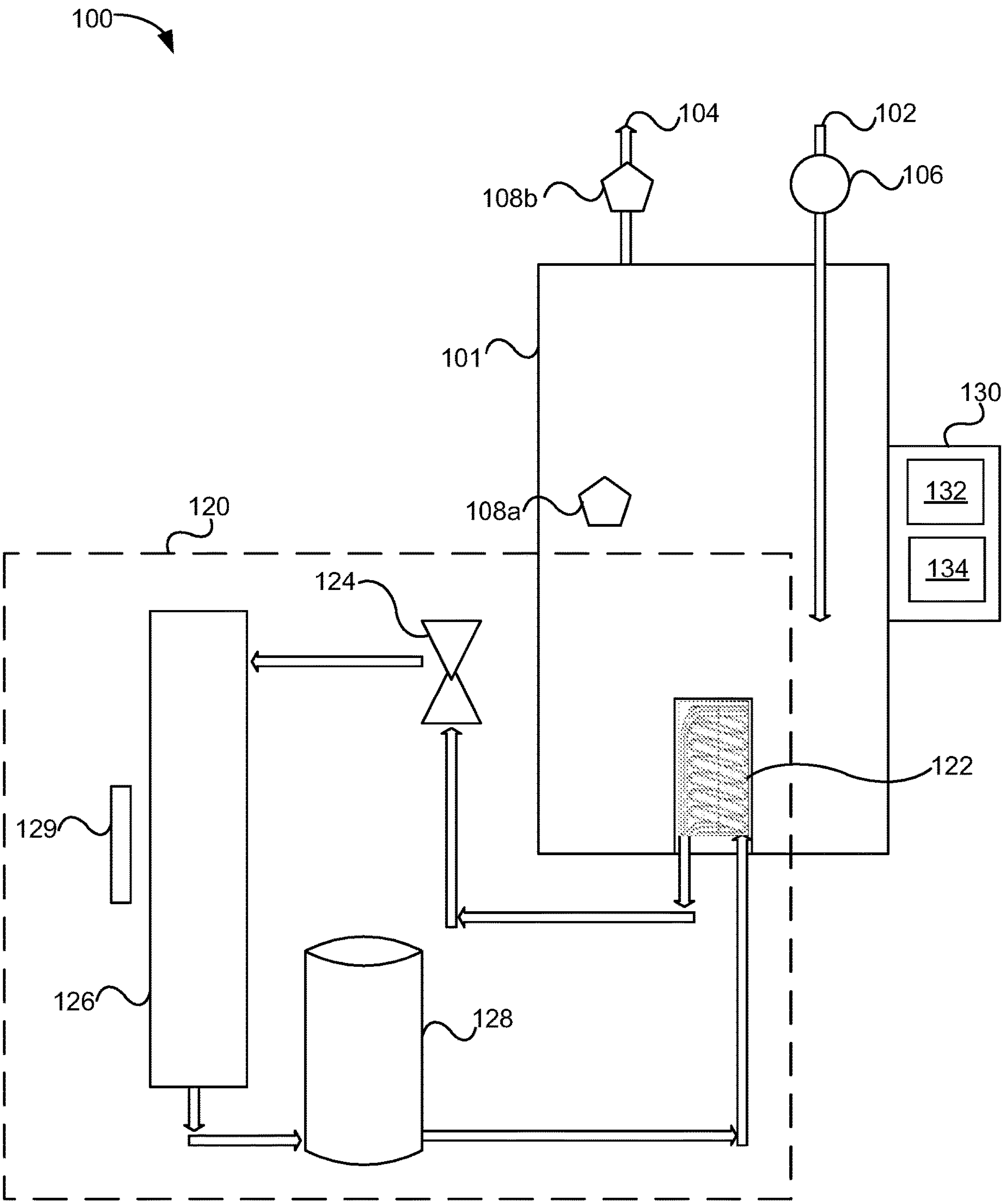

100
104
102
108b
106
101
130
132
134
120
108a
124
122
129
126
128

FIG. 1

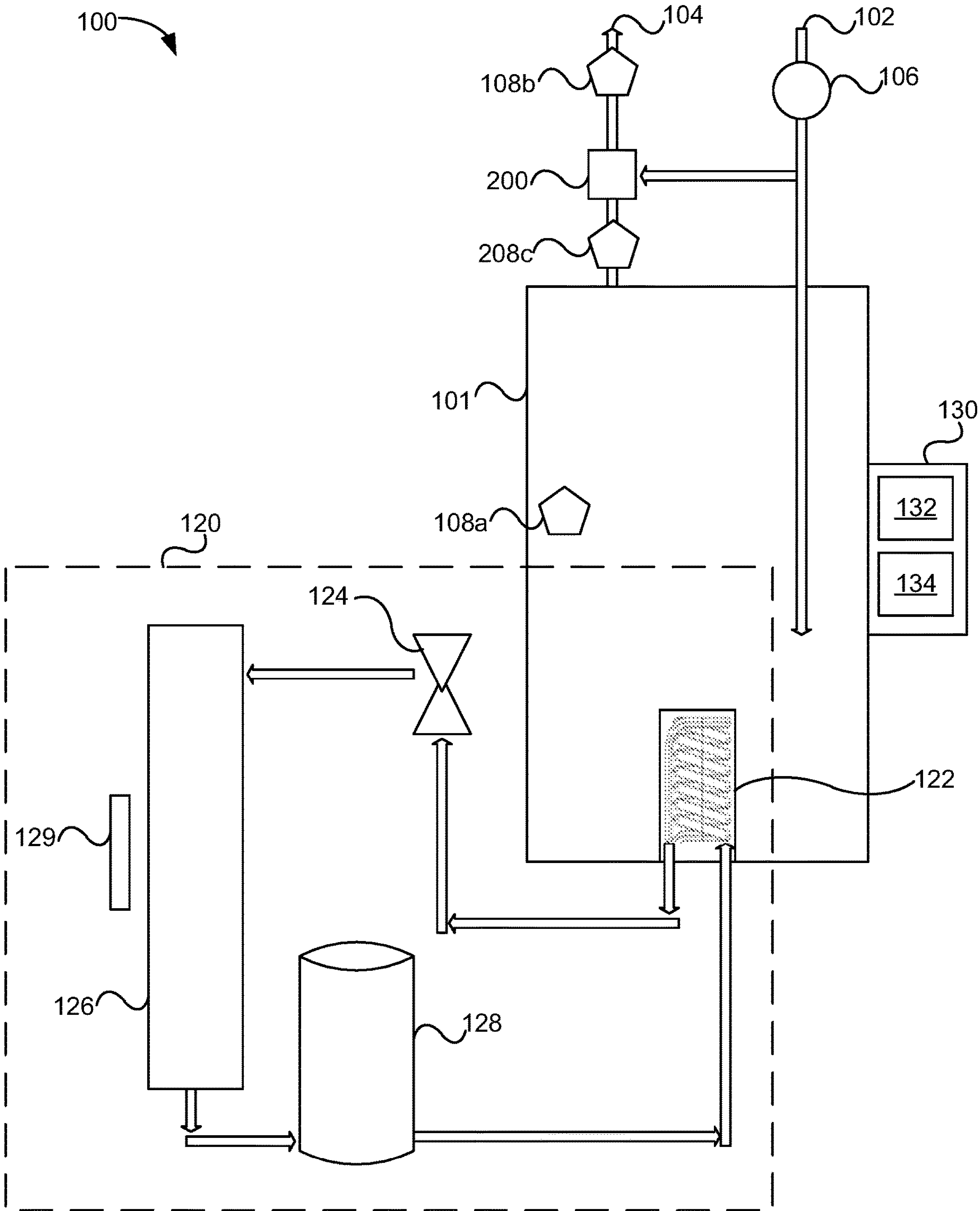

100
104
102
108b
106
200
208c
101
130
132
134
108a
120
124
122
129
126
128

FIG. 2

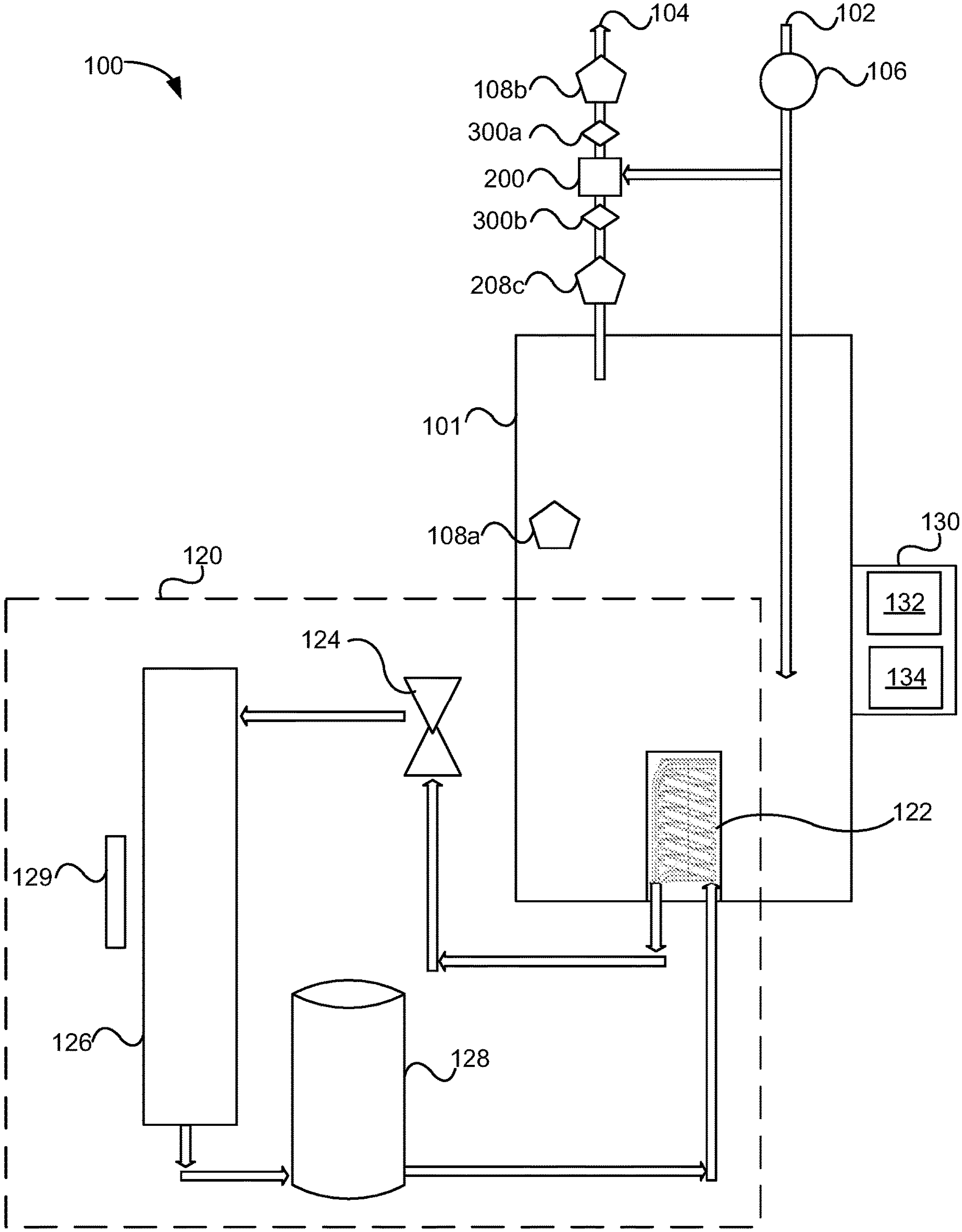

100
104
102
108b
106
300a
200
300b
208c
101
108a
130
132
134
120
124
122
129
126
128

FIG. 3

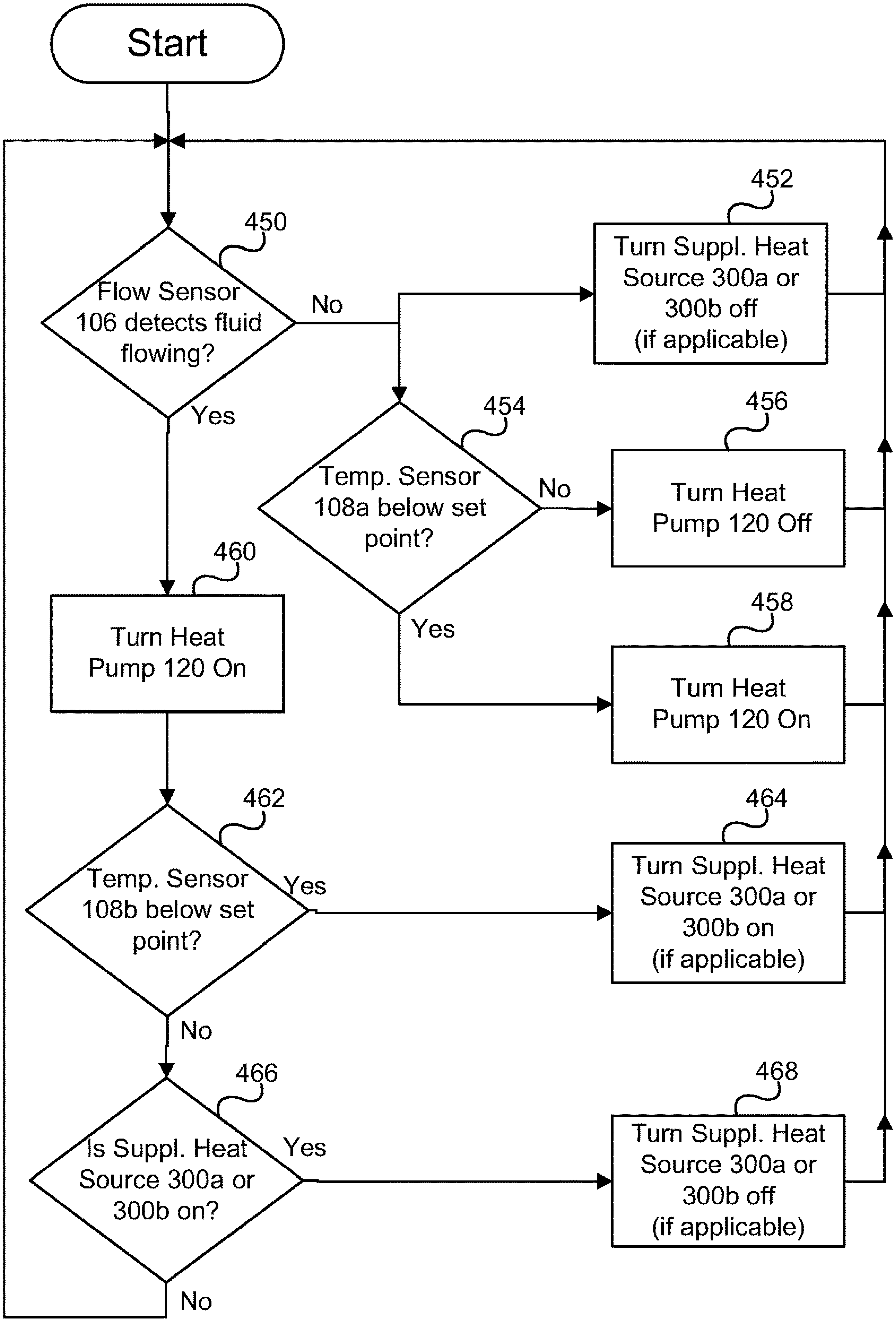

Start
450
Flow Sensor 106 detects fluid flowing?
No
Yes
452
Turn Suppl. Heat Source 300a or 300b off (if applicable)
454
Temp. Sensor 108a below set point?
No
Yes
456
Turn Heat Pump 120 Off
458
Turn Heat Pump 120 On
460
Turn Heat Pump 120 On
462
Temp. Sensor 108b below set point?
Yes
No
464
Turn Suppl. Heat Source 300a or 300b on (if applicable)
466
Is Suppl. Heat Source 300a or 300b on?
Yes
No
468
Turn Suppl. Heat Source 300a or 300b off (if applicable)

FIG. 4

ON-DEMAND HEAT PUMP WATER HEATER

FIELD OF TECHNOLOGY

Embodiments of the present disclosure relate generally to water heaters, and, more particularly, to on-demand water heaters which utilize a heat pump to heat the fluid.

BACKGROUND

It is common for water to be heated for many reasons, including water sanitation, cooking, and providing a more pleasing water temperature. Currently, the most common methods to heat the water utilize combustible matter or electrical heating elements as the heat source. No matter the method, it is necessary to add energy to the water to increase the water's temperature. The process of adding energy to the water to increase its temperature has inefficiencies associated with it which can be costly and time consuming. Therefore, it is desirable to heat the water as efficiently as possible.

One solution to this problem is to use a large insulated storage tank to store heated water and periodically add heat as the water temperature falls. This can provide a steady source of heated water without requiring a constant energy source. However, this solution is generally inefficient because energy is lost from the moment the water is heated, including when the water is not in use. Furthermore, this solution typically requires a large storage tank, which can often be too large to store near the location where the heated water is needed. This can cause further inefficiency because heat can dissipate as the heated water travels through pipes to the desired location for use.

A more recently developed energy source, known as a heat pump, is capable of transferring energy to water stored in a storage tank in a way that is typically more efficient than combustible matter or electrical heating elements. Rather than create the thermal energy directly, such as by combustible matter or electrical heating element energy sources, a heat pump can move thermal energy from a source of heat to a heat reservoir resulting in increased energy efficiency. In the case of heat pump water heaters, the water in the storage tank becomes the heat reservoir. Most commonly, a heat pump utilizes the vapor-compression cycle of a refrigerant to transfer thermal energy to the water in the storage tank. However, even though a heat pump is typically more energy efficient than methods using combustible matter or electrical heating elements, heat pump systems can still lose a substantial amount of energy during the process of maintaining the water in a storage tank at a desired heated temperature and then delivering that heated water to a location of use that is usually a distance away from the storage tank.

More recent water heater designs have reduced the need for a large storage tank and heat the water only when heated water is demanded. These on-demand water heaters, also known as "instantaneous" or "tankless" water heaters, supply heat only when required, which can reduce the amount of energy lost by the water heating system when the water heater is not in use. Furthermore, because on-demand water heaters do not require a large storage tank, they can be considerably smaller than traditional water heaters. The reduced size allows on-demand water heaters to be placed closer to where the heated water is needed and further reduces heat loss from water traveling through cold pipes. Because traditional energy sources, like combustible matter and electrical heating elements, are generally known to heat water quicker than a heat pump, existing on-demand water

heaters typically use combustible matter or electrical heating elements. However, such heating elements can generally require a large amount of energy to operate.

Accordingly, there is a need for on-demand water heaters providing increased energy efficiency than those currently available. This and other problems are addressed by embodiments of the technology disclosed herein.

BRIEF SUMMARY

The disclosed technology can include a fluid heating device having a heat pump configured to heat a fluid (e.g., water) based on a predetermined temperature setting and predetermined flow rate.

The fluid heating device can have a low fluid capacity heating chamber having a fluid inlet, a fluid outlet, a heat pump for heating the fluid, and a controller configured to control the temperature of the fluid based on a predetermined temperature setting by controlling the heat pump.

The low fluid capacity heating chamber can include a fluid capacity of less than or equal to approximately 15 gallons. The low fluid capacity heating chamber can include a fluid capacity of less than or equal to approximately 10 gallons. The low fluid capacity heating chamber can include a fluid capacity of less than or equal to approximately 5 gallons. The low fluid capacity heating chamber can be configured to have a fluid capacity of less than or equal to approximately 2 gallons.

The fluid heating device can include one or more temperature sensors that can be configured to detect a temperature of the fluid.

The fluid heating device can include a flow sensor that can be configured to detect a flow of the fluid.

The fluid heating device can include a fluid mixing valve, which can be configured to control the temperature of the fluid. The fluid mixing valve can be controlled by the controller that controls the heat pump or by a separate controller.

The fluid heating device can include a supplemental heat source that can be configured to heat the fluid. The supplemental heat source can be controlled by the controller that controls the heat pump. Alternatively, the supplemental heat source can be controlled by a different controller associated with the supplemental heat source.

The fluid heating device can include a ventilation system that is configured to cool the heat pump.

The disclosed technology includes a method of controlling a fluid heating system. The method can include detecting, by a flow sensor, flow data of the fluid as well as detecting, by a temperature sensor, temperature data of the fluid. The method can include the controller outputting instructions to the heat pump in response to determining that the flow data indicates a positive flow of the fluid or that the temperature data indicates the fluid temperature is less than a predetermined temperature setting.

The method can include the controller outputting instructions to the controller to heat the fluid in response to determining that the fluid temperature cannot be maintained at a predetermined temperature setting for a predetermined time based on the flow data and the temperature data.

The method can include the controller outputting adjustment instructions to the fluid mixing valve in response to determining that the fluid temperature is outside of a predetermined temperature range.

The method can also include the controller outputting instructions to a supplemental heat source to heat the fluid in response to determining that the fluid temperature is less than a predetermined temperature setting.

The disclosed technology includes a system comprising a low fluid capacity heating chamber, a controller, and a memory storing instructions that, when executed, cause the controller to perform certain actions. For example, the controller, as directed by the instructions, can receive flow data from a flow sensor and temperature data from a temperature sensor. The flow data can be indicative of a flow of fluid (e.g., water) at a location of the flow sensor, and the temperature data can be indicative of a temperature of the fluid at a location of the temperature sensor. The controller, as directed by the instructions, can output a heat pump control signal in response to determining that (i) the flow data indicates a positive flow rate or (ii) the temperature data indicates a fluid temperature (e.g., water temperature) that is lower than a predetermined temperature setting.

The instructions can cause the controller to output another heat pump control signal in response to determining that the fluid temperature cannot be maintained at a predetermined temperature setting for a predetermined amount of time, based on the flow data indicating a positive flow of the fluid and temperature data indicating the fluid temperature is lower than a predetermined temperature setting.

The instructions can cause the controller to output a fluid mixing valve control signal in response to determining that the temperature data indicates a water temperature that is outside of a predetermined temperature range.

The instructions can cause the controller to output a supplemental heat source control signal in response to determining that the temperature data indicates a water temperature that is lower than a predetermined temperature.

Additional features, functionalities, and applications of the disclosed technology are discussed herein in more detail.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate multiple embodiments of the presently disclosed subject matter and serve to explain the principles of the presently disclosed subject matter. The drawings are not intended to limit the scope of the presently disclosed subject matter in any manner.

FIG. **1** is a schematic view of an on-demand heat pump water heater, in accordance with the presently disclosed technology.

FIG. **2** is a schematic view of an on-demand heat pump water heater with a mixing valve, in accordance with the presently disclosed technology.

FIG. **3** is a schematic view of an on-demand heat pump water heater with a mixing valve and a supplemental heat source, in accordance with the presently disclosed technology.

FIG. **4** is a logic diagram of an on-demand heat pump water heater system, in accordance with the presently disclosed technology.

DETAILED DESCRIPTION

The disclosed technology relates to an efficient on-demand fluid heater having a heat pump to heat fluid (e.g., water). Existing on-demand water heaters are generally more efficient than traditional large storage tank water heaters because they typically heat the water only when necessary and can thus reduce the amount of heated water kept in a storage tank. Because on-demand water heaters do not require a large capacity storage tank, they can be installed much closer to the point of use, which can further reduce the amount of heat lost while in transit to the user (e.g., while traveling through a network of pipes). The on-demand fluid heaters disclosed herein (which includes on-demand water heaters) can provide improved heating efficiencies as compared to existing systems, which can in turn provide lower operating costs to a user.

Examples of the present disclosure relate to on-demand fluid heaters which utilize a heat pump as the heat source. Examples of the disclosed technology are discussed herein with reference to heating "fluid" or "water." It is to be appreciated that the disclosed technology can be used with a variety of fluids, including water. Thus, while some examples may be described in relation to heating water specifically, all examples of the disclosed technology can be used with fluids other than water unless otherwise specified. Although certain examples of the disclosed technology are explained in detail, it is to be understood that other examples are contemplated. Accordingly, it is not intended that the disclosed technology be limited in its scope to the details of construction and arrangement of components set forth in the following description or illustrated in the drawings. The disclosed technology is capable of other embodiments and of being practiced or carried out in various ways. Also, in describing the many examples, specific terminology will be resorted to for the sake of clarity.

It should also be noted that, as used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural references unless the context clearly dictates otherwise. References to a composition containing "a" constituent is intended to include other constituents in addition to the one named.

Also, in describing the example embodiments, terminology will be resorted to for the sake of clarity. It is intended that each term contemplates its broadest meaning as understood by those skilled in the art and includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

Ranges may be expressed herein as from "about" or "approximately" or "substantially" one particular value and/or to "about" or "approximately" or "substantially" another particular value. When such a range is expressed, other example embodiments include from the one particular value and/or to the other particular value.

Herein, the use of terms such as "having," "has," "including," or "includes" are open-ended and are intended to have the same meaning as terms such as "comprising" or "comprises" and not preclude the presence of other structure, material, or acts. Similarly, though the use of terms such as "can" or "may" are intended to be open-ended and to reflect that structure, material, or acts are not necessary, the failure to use such terms is not intended to reflect that structure, material, or acts are essential. To the extent that structure, material, or acts are presently considered to be essential, they are identified as such.

It is also to be understood that the mention of one or more method steps does not preclude the presence of additional method steps or intervening method steps between those steps expressly identified. Moreover, although the term "step" may be used herein to connote different aspects of methods employed, the term should not be interpreted as implying any particular order among or between various steps herein disclosed unless and except when the order of individual steps is explicitly required.

The components described hereinafter as making up various elements of the disclosed technology are intended to be illustrative and not restrictive. Many suitable components that would perform the same or similar functions as the components described herein are intended to be embraced within the scope of the disclosed technology. Such other components not described herein can include, but are not limited to, for example, similar components that are developed after development of the presently disclosed subject matter.

To facilitate an understanding of the principles and features of the disclosed technology, various illustrative examples are explained below. In particular, the presently disclosed subject matter is described in the context of being an on-demand heat pump water heater. The present disclosure, however, is not so limited, and can be applicable in other contexts. For example and not limitation, the disclosed technology may improve other fluid heating systems, whether considered on-demand or not. Such examples and/or applications are contemplated within the scope of the present disclosure. Accordingly, when the present disclosure is described in the context of a deployment system for an on-demand heat pump water heater, it will be understood that other embodiments can take the place of those referenced.

Referring now to the drawings, in which like numerals represent like elements, example embodiments of the present disclosure are herein described.

FIG. **1** is a schematic view of an example on-demand heat pump water heater **100** that includes a low fluid capacity heating chamber **101**, a fluid inlet **102**, a fluid outlet **104**, a flow sensor **106**, a temperature sensor (e.g., one or both of temperature sensors **108***a*, **108***b*), a heat pump **120**, and a controller **130**. The heat pump **120** comprises a condenser **122**, an expansion valve **124**, an evaporator **126**, and a compressor **128**. Optionally, the heat pump can include or be in communication with a ventilation system **129** to cool the heat pump **120**. The controller **130** can control the heat pump **120** to maintain the temperature of the fluid at a predetermined temperature setting (e.g., a predetermined value, a predetermined range of values) by analyzing data received from the flow sensor **106** and/or the temperature sensor(s) **108***a*, **108***b*. One of skill in the art will understand that FIG. **1** is an example for illustrative purposes and that the various components of the on-demand heat pump water heater **100** can be arranged in various orders, locations, and configurations.

Although commonly referred to as "tankless" water heaters, on-demand water heaters often use some form of small storage tank in which to heat the water. The low fluid capacity heating chamber **101** can be used as a temporary storage location for the heat pump **120** to add heat to the water. The low fluid capacity heating chamber **101** can be sized for various applications. For example, the low fluid capacity heating chamber **101** can have a capacity of fifteen gallons or less for a typical usage application. As another example, the low fluid capacity heating chamber **101** can be sized between one and two gallons for use with a bathroom sink in a user's home, as based on the average user's demand for hot water. Depending on the application, the low fluid capacity heating chamber **101** can have a capacity of 0.25 gallons, 0.5 gallons, 1 gallon, 1.5 gallons, 2, gallons, 2.5 gallons, 3 gallons, 3.5 gallons, 4 gallons, 4.5 gallons, 5 gallons, or any other appropriate size to fit the particular application. For example, the low fluid capacity heating chamber **101** can have a capacity of ten gallons, fifteen gallons, or more. The low fluid capacity heating chamber **101** can be sized to meet Department of Energy (DOE) conservation standards for consumer water heaters. For example, the low fluid capacity heating chamber can be less than 2 gallons to meet DOE standards for electric instantaneous water heaters found in 10 C.F.R. 430.32(d). The low fluid capacity heating chamber **101** can be made of any suitable material for storing and heating water, including copper, carbon steel, stainless steel, ceramics, polymers, composites, or any other appropriate material. Furthermore, the low fluid capacity heating chamber **101** can be treated or lined with a coating to prevent corrosion and leakage. An appropriate treating or coating will be capable of withstanding the demand temperature of the heated water and pressure of the system and can include, as non-limiting examples, glass enameling, galvanizing, thermosetting resin-bonded lining materials, thermoplastic coating materials, cement coating, or any other appropriate treating or coating for the application. Optionally, the low fluid capacity heating chamber **101** can be insulated to retain heat. For example, the low fluid capacity heating chamber **101** can also be insulated using fiberglass, aluminum foil, organic material, or any other appropriate insulation material.

As shown in FIG. **1**, the disclosed technology can include a heat pump **120** to heat water. The heat pump **120** can be any suitable form of heat pump that can be used to heat water, including compression- or absorption-type heat pumps. The heat pump **120** can be adapted to use an air source, ground source, water source, or any other heat source. The heat pump **120** can also be a geothermal, air-to-water, water-to-water, liquid-to-water, or any other type of heat pump system that is appropriate for the particular application. As an example, the heat pump **120** can be an air source type heat pump, which utilizes a refrigerant in a vapor-compression cycle, but the type of heat source can be modified depending on the particular application. Furthermore, the heat pump **130** can be a single-stage, two-stage, or variable capacity heat pump, depending on the application.

The heat pump **120** can include a condenser **122**, an expansion valve **124**, an evaporator **126**, and a compressor **128**. The various components can be sized, shaped, and located as is appropriate for the particular application. For example, the compressor **128** can be powered by any appropriate energy source, including electrical power, a combustion engine, or any other energy source capable of operating the compressor **128**. The compressor **128** can be any type of compressor. For example, the compressor **128** can be a positive displacement compressor, a reciprocating compressor, a rotary screw compressor, a rotary vane compressor, a rolling piston compressor, a scroll compressor, a diaphragm compressor, a dynamic compressor, an axial compressor, or any other form of compressor that can be integrated into a heat pump. The condenser **122** can be installed in a position that improves energy transfer to the water in the low fluid capacity heating chamber **122**. On the other hand, the evaporator **126** can be located where it can absorb heat from its surroundings. As discussed above, this can include any heat source, such as air, water, or geothermal sources. Both the condenser **122** and the evaporator **126** can be made of material(s) that can effectively exchange heat, including copper, aluminum, stainless steel, gold, silver, gallium, indium, thallium, graphite, composite materials, or any other material that is appropriate for a given application. A given application can have specific system requirements, such as, as non-limiting examples, the desired water temperature, heat transfer rate (e.g., Btu/hr required to heat the source water), environmental conditions (e.g., the climate in which the system is installed), and cost considerations. Furthermore, the expansion valve can be any type of expansion valve. For example, the expansion valve **124** can be a thermal expansion valve, a manual expansion valve, an automatic expansion valve, an electronic expansion valve, a low-pressure float valve, a high-pressure float valve, capillary tubes, or any other form of expansion valve appropriate for the application. The size, type, and installed location of the expansion valve **124** can vary depending on the application, which can be influenced by the above system requirements or other considerations.

The on-demand heat pump water heater **100** can include various sensing devices that collect data about the water in the system. FIG. **1** shows a flow sensor **106** and temperature sensors **108***a*, **108***b*. The flow sensor **106** is shown as being installed just downstream of the fluid inlet **102** but can be installed in alternative locations that are in fluid communication with the low fluid capacity heating chamber **101**. For example, the flow sensor **106** can be installed just downstream of the fluid inlet, inside the low fluid capacity heating chamber **101**, downstream of the low fluid capacity heating chamber **101**, or even upstream of the fluid inlet **102** or downstream of the fluid outlet **104** so long as the flow sensor **106** is able to detect a positive flow (fluid flowing through the low fluid capacity heating chamber **101** in the direction from the fluid inlet **102** and toward the fluid outlet **104**) of a fluid flowing into the low fluid capacity heating chamber **101**. Regardless of position, the flow sensor **106** can detect the flow rate of the fluid at the location of the flow sensor and can transmit flow data indicative of the flow rate to the controller **130**. The flow sensor **106** can be any type of flow sensor and can be configured to simply detect fluid flow or can be used to detect rate of flow of the fluid. If it is desirable to simply measure the presence of fluid flow, the flow sensor **106** can be a flow switch. If the flow sensor **106** is a flow switch, it can be a vane actuated flow switch, a disc actuated flow switch, a liquid flow switch, or any other appropriate type of flow switch for the application. If it is desirable to measure the rate of fluid flow, the flow sensor **106** can be a flow meter or another type of rate-measuring flow sensor. For example, the flow sensor **106** can be a differential pressure flow meter, a positive displacement flow meter, a velocity flow meter, a mass flow meter, an open channel flow meter, or any other type of flow meter configured to measure flow rate of a fluid. The type of flow sensor **106** used will depend on the type of fluid being measured, its temperature and pressure, viscosity, conductivity, corrosiveness, and cleanliness required of the system.

Similar to the flow sensor **106**, the temperature sensor(s) **108***a*, **108***b* can be installed in any appropriate location that allows the temperature sensor(s) **108***a*, **108***b* to detect temperature data of fluid at the installed location of the temperature sensor(s) **108***a*, **108***b*. Although two temperature sensors **108***a* and **108***b* are shown in FIG. **1**, the on-demand heat pump water heater **100** can include only a single temperature sensor. For example, the on-demand heat pump water heater **100** can include only temperature sensor **108***a* to measure the temperature of the fluid within the low fluid capacity heating chamber **101**, or the on-demand heat pump water heater **100** can include only temperature sensor **108***b* to measure the temperature of the fluid exiting the low fluid capacity heating chamber **101**. Alternatively, the on-demand heat pump water heater **100** can include two temperature sensors as depicted in FIG. **1**, or can include three, four, five, or more temperature sensors (e.g., as depicted in FIGS. **2** and **3** and as discussed more fully below).

Referring to the dual temperature sensor example shown in FIG. **1**, one temperature sensor **108***a* can be installed in the low fluid capacity heating chamber **101** to detect a

temperature of the fluid inside the low fluid capacity heating chamber **101**, which can be representative of an average temperature of the fluid within the low fluid capacity heating chamber **101**. The temperature of the fluid within the low fluid capacity heating chamber **101** will typically be highest near the heat pump **120** and lowest near the fluid inlet **102**. Therefore, the temperature sensor **108***a* can be positioned in a location that best represents the average temperature of the fluid, which can be useful to ensure the water is being heated to the proper temperature while water is or is not flowing through the water heater **100**. Another temperature sensor **108***b* can be installed downstream of the low fluid capacity heating chamber **101** (e.g., at fluid outlet **104**) and can be configured to monitor the temperature of the water exiting the low fluid capacity heating chamber **101**, which can be useful to ensure the water is being heated to the proper temperature while water is being drawn through the system.

The temperature sensor(s) **108***a*, **108***b* can be any type of sensor capable of measuring temperature of a fluid and providing temperature data indicative of the fluid temperature to the controller **130**. For example, the temperature sensor(s) **108***a*, **108***b* can be thermocouples, resistor temperature detectors, thermistors, infrared sensors, semiconductors, or any other type of sensors which would be appropriate for a given use or application. All temperature sensors of the system can be the same type of temperature sensor, or the system can include different types of temperature sensors. For example, temperature sensor **108***a* can be a thermocouple and temperature sensor **108***b* can be a thermistor. One skilled in the art will appreciate that the type, location, and number of temperature sensors can vary depending on the application.

The heat pump **120** can be controlled by a controller **130**. The controller **130** can be a computing device configured to receive data, determine actions based on the received data, and output a control signal instructing one or more components of the system to perform one or more actions. Although shown in FIG. **1** as being mounted to the low fluid capacity heating chamber **101**, one of skill in the art will understand that the controller **130** can be installed in any location, provided the controller **130** is in communication with at least some of the components of the system. This can include installation in or on an enclosure including one or more of the other components depicted in FIG. **1** or installation at a remote location physically separated from the components shown in FIG. **1**. Furthermore, the controller **130** can be configured to send and receive wireless or wired signals; the controller **130** can be configured to send and receive analog or digital signals. The wireless signals can include Bluetooth™, BLE, WiFi™, ZigBee™, infrared, microwave radio, or any other type of wireless communication as may be appropriate for the particular application. The hard-wired signal can include any directly wired connection between the controller and the other components. For example, the controller **130** can have a hard-wired 120-volt connection to the heat pump **120** which directly energizes the heat pump. Alternatively, the components can be powered directly and receive control instructions from the controller **130** via a digital connection. The digital connection can include a connection such as an Ethernet or a serial connection and can utilize any appropriate communication protocol for the application such as Modbus, fieldbus, PROFIBUS, SafetyBus p, Ethernet/IP, or any other appropriate communication protocol for the application. Furthermore, the controller **130** can utilize a combination of wireless, hard-wired, and digital communication signals to communicate with and control the various components. One of skill in the art will appreciate that the above configurations are given merely as non-limiting examples and the actual configuration may vary depending on the application.

The controller **130**, can include memory **132**, which can store a program and/or instructions associated with the functions described herein, and can include a processor **134** configured to execute the program and/or instructions. The memory **132** can include one or more suitable types of memory (e.g., volatile or non-volatile memory, random access memory (RAM), read only memory (ROM), programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, flash memory, a redundant array of independent disks (RAID), and the like) for storing files including the operating system, application programs (including, for example, a web browser application, a widget or gadget engine, and or other applications, as necessary), executable instructions and data. One, some, or all of the processing techniques described herein can be implemented as a combination of executable instructions and data within the memory.

The processor **134** can be one or more known processing devices, such as a microprocessor from the Pentium™ family manufactured by Intel™, the Turion™ family manufactured by AMD™, or the Cortex™ family or SecurCore™ manufactured by ARM™. The processor can constitute a single-core or multiple-core processor that executes parallel processes simultaneously. For example, the processor **134** can be a single core processor that is configured with virtual processing technologies. One of ordinary skill in the art would understand that other types of processor arrangements could be implemented that provide for the capabilities disclosed herein.

As depicted in FIG. **1**, the controller **130** can be configured to receive data from the flow sensor **106** and one or more temperature sensors **108***a*, **108***b*. The controller **130** can be configured to engage the heat pump **120** and other components only when necessary, which can reduce the amount of power required to operate the system over a given period of time (e.g., a year). For example, the controller **130** can receive flow data from the flow sensor **106**, determine whether the flow data indicates a positive flow rate, and activate the heat pump **120** if the fluid in the system has begun to flow. Alternatively or in addition, the controller **130** can receive temperature data from a temperature sensor **108***a*, **108***b*, determine whether the temperature data indicates a temperature that is less than a predetermined temperature setting, and activate the heat pump **120** if the detected temperature is less than the predetermined temperature setting (a "low temperature"). The controller **130** can determine the detected temperature is a low temperature based on one, some, or all of the temperature sensors **108***a*, **108***b* of the on-demand heat pump water heater **100**, which can correspond to the detected water temperatures at multiple positions throughout the on-demand heat pump water heater **100**. For example, the controller **130** can be configured to engage the heat pump **120** if any single temperature sensor **108***a*, **108***b* detects a low temperature. As another example, the controller **130** can be configured to engage the heat pump **120** only if all temperature sensors **108***a*, **108***b* detect a low temperature. As yet another example, the controller **130** can be configured to engage the heat pump **120** if a predetermined number (e.g., a majority) of temperature sensors **108***a*, **108***b* detect a low temperature. As yet another example, the controller **130** can be configured to engage the heat pump if a predetermined combination of temperature sensors **108***a*, **108***b* detect a low temperature. That is, the controller **130** can be configured to weigh data from a given temperature sensor more heavily than data from another temperature sensor, based on the location, type, accuracy, or other aspect of the temperature sensors.

The controller **130** can be configured to receive temperature data from a temperature sensor **108***a*, **108***b* and flow data from a flow sensor **106** and can determine whether the fluid can be maintained at the predetermined temperature for a predetermined amount of time based on the current temperature, flow rate, and/or output of the heat pump **120**. This can enable the controller **130** to, for example, adjust the performance of the heat pump **120** to improve the efficiency of the system and/or prevent damage to the heat pump **120** or other components. Thus, if the heat pump **120** is a two-stage or variable capacity heat pump, the controller **130** can adjust the control signal to the heat pump **120** to vary its performance and the amount of heat transferred to the fluid. For example, if the controller **130** received flow data from the flow sensor **106** that indicated the fluid was flowing at a rate of 1.5 gallons per minute and received data from a temperature sensor **108***b* indicating that the current temperature of the fluid downstream of the low fluid capacity heating chamber **101** was 120° F., the controller **130** could determine whether the fluid could be maintained at a predetermined temperature setting for a predetermined amount of time (e.g., 1 minute, 2 minutes, 3 minutes, 5 minutes) based on the flow rate data (e.g., 1.5 gal/min), the temperature data (e.g., 120° F.), and/or known performance capabilities of the heat pump **120**. If the controller **130** determines that the current heat pump **120** output would be inadequate to maintain the water temperature at the predetermined temperature setting, the controller **130** can transmit a control signal to the heat pump **120** indicating that the heat pump **120** should operate at a higher output (or a control signal instructing the heat pump **120** to disengage if the controller **120** determines that operation at a higher output would damage the heat pump **120** or other components of the on-demand heat pump water heater **100**).

The controller **130** can be configured to monitor temperature data from a temperature sensor **108***a* to ensure the temperature of the fluid inside the low fluid capacity heating chamber **101** is maintained at a predetermined temperature setting even when no fluid is flowing. Accordingly, the controller **130** can be configured to ensure the water inside the low fluid capacity heating chamber **101** is heated and ready for use. By pre-heating water, the system can provide the user with a source of immediately available heated water, which can provide additional time for the on-demand heat pump water heater **100** to heat incoming water for further use.

As briefly discussed above, the controller **130** can be configured to determine actions based on data received from the flow sensor **106** and/or the temperature sensor(s) **108***a*, **108***b*. The controller **130** can be configured to maintain the temperature of fluid in the low fluid capacity heating chamber within a predetermined temperature range. For example, the predetermined temperature range can be from approximately 105° F. to approximately 135° F. When the temperature of the fluid falls below the lower endpoint of the predetermined temperature range (e.g., approximately 105° F.), the controller **130** can be configured to send a control signal to the heat pump **120** to energize the heat pump **120** and raise the temperature of the fluid. The control **130** can instruct the heat pump **120** to raise the temperature of the fluid until a predetermined fluid temperature is reached, such as a midpoint value between the endpoints of the predetermined temperature range (e.g., approximately 120° F. in the immediate example). Similarly, when the temperature of the fluid rises above the upper endpoint of the predetermined temperature range (e.g., approximately 135° F.), the controller **130** can send a control signal to the heat pump **120** to de-energize the heat pump and cease adding heat to the fluid. The controller **130** can instruct the heat pump **120** to cease adding heat to the fluid until a predetermined fluid temperature is reached, such as a midpoint value between the endpoints of the predetermined temperature range (e.g., approximately 120° F.).

As another example, the controller **130** can be configured to maintain the fluid in the low fluid capacity heating chamber within a smaller temperature range to ensure the water is closer to a desired temperature value when demanded. For example, the predetermined temperature range can be from approximately 123° F. to approximately 127° F., and the predetermined temperature range can correspond to a target temperature value of approximately 125° F. When the temperature of the fluid falls below 123° F., the controller **130** can send a control signal to the heat pump **120** to energize the heat pump **120** and raise the temperature of the fluid. Similarly, when the temperature of the fluid rises above 127° F., the controller **130** can send a control signal to the heat pump **120** to de-energize the heat pump and cease adding heat to the fluid. The given example temperature ranges are merely for illustration and can vary depending on the given application.

Furthermore, the controller **130** can be configured to determine and instruct multiple actions on the received temperature data and the received flow data. For example, the controller **130** can be configured to maintain the fluid within the low fluid capacity heating chamber **101** between 115° F. to 126° F. when water is not flowing and between 124° F. to 130° F. when the water is flowing. One of skill in the art will understand that these temperature ranges and instructions provided by the controller **130** are offered merely as example and that the actual configuration can be varied depending on the application.

FIG. **1** also depicts an optional ventilation system **129**, which can be used to cool certain components of the heat pump **120**. The ventilation system **129** can be installed directly on the on-demand heat pump water heater **100** or it can be installed nearby to facilitate cooling. For example, the ventilation system **129** can be installed on a door or wall of a housing in or on which the on-demand heat pump water heater **100** is installed (e.g., on the wall or door of the cupboard below a sink where the on-demand heat pump water heater **100** is installed). The ventilation system **129** can be configured to operate continuously, while the heat pump **120** is operating, once the fluid temperature has reached a predetermined temperature setting, or any combination thereof. The ventilation system **129** can be controlled by the controller **130** or can be controlled by a dedicated control system separate from the controller **130**. If the ventilation system **129** has its own controller, the ventilation system's **129** controller can be in communication with the controller **130** (e.g., to receive temperature data or an indication that the heat pump **120** is engaged). Furthermore, the ventilation system **129** can be an active ventilation system, such as a mechanical fan, or a passive venting system, such as a vent or louver.

FIG. **2** is a schematic view of an example on-demand heat pump water heater **100** including a mixing valve **200** and an additional temperature sensor **208***c*. The mixing valve **200** and temperature sensor **208***c* can be useful to provide more precise temperature control of the fluid delivered at the point of use as compared to, for example, the example depicted by FIG. **1**; however, the additional components may also raise the overall cost and complexity of the system.

The mixing valve **200** can be any type of mixing valve. For example, the mixing valve **200** can be a thermostatic mixing valve, a tempering valve, a pressure balanced valve, an electronically-controlled mixing valve, or any other type of mixing valve as would be appropriate for the application. The mixing valve **200** can be passive or active in controlling the water output temperature. For example, the mixing valve **200** can be manually controlled and intended to be set at the proper setting upon installation and adjusted as required or desired by the user. Alternatively, the mixing valve **200** can be an electronically-controlled mixing valve that is configured to receive an input signal from the controller **130** and adjust its position or configuration (e.g., how "open" the valve is) to achieve the desired water temperature. The appropriate type of mixing valve can depend on the particular application, environmental factors, and other aspects of the on-demand heat pump water heater **100**.

The mixing valve **200** can be a thermostatic mixing valve, which can be set to ensure the temperature of water exiting the fluid outlet **104** of the on-demand heat pump water heater **100** is within a predetermined temperature range. The thermostatic mixing valve can adjust the position or configuration of the mixing valve depending on the temperature of the water exiting the fluid outlet **104** and would do so without any input from the controller. As another example, the mixing valve **200** can be an electronically controlled mixing valve and be configured to adjust its position depending on control signals received from the controller **130**. For example, the controller **130** can send a control signal to the mixing valve **200** to adjust its position or configuration to ensure water exiting the fluid outlet **104** of the on-demand heat pump water heater **100** is within a predetermined temperature range. One of skill in the art will understand that the exact type and configuration of mixing valve **200** can be varied to achieve the desired result depending on the application and that the above examples are given merely for illustrative purposes. Furthermore, it is contemplated that the mixing valve **200** (e.g., an electronically controlled mixing valve) can be controlled by the controller **130** or by a separate controller (e.g., a controller dedicated to control of the mixing valve **200**) If the mixing valve **200** has a dedicated controller, the dedicated mixing valve controller can be in communication with the controller **130** or other components of the on-demand heat pump water heater **100**.

The temperature sensor **208***c* can be any type or configuration of temperature sensor as discussed above with respect to temperature sensors **108***a*, **108***b*. The inclusion of temperature sensor **208***c* can provide an additional temperature measurement of the temperature of the fluid exiting the low fluid capacity heating chamber **101** and entering the mixing valve **200**. As an example, the temperature sensor **208***c* can be used in conjunction with a mixing valve **200** which is electronically controlled. In this example, the controller **130** can receive temperature data from the temperature sensor **208***c*, which is indicative of the temperature of the fluid exiting the low fluid capacity heating chamber **101** and entering the mixing valve **200**. The controller **130** can determine the proper position of the mixing valve **200** based on the received temperature data and can send a control signal to the mixing valve **200** to adjust the position of the mixing valve **200**, ensuring the temperature of the fluid exiting the fluid outlet **104** is within a predetermined temperature range. The controller **130** can also make this determination by considering flow data received from the flow sensor **106** and/or temperature data received from any of the temperature sensors **108***a*, **108***b*, and **208***c*. One of skill in the art will understand that the actual configuration of the components depicted in FIG. **2** can be arranged in different configurations and achieve similar results.

FIG. **3** is a schematic view of an on-demand heat pump water heater **100** including supplemental heat sources (e.g., supplemental heat source **300***a* and **300***b*), which can be used to supply additional heat to the fluid. The supplemental heat sources **300***a* and/or **300***b* can provide increased precision of temperature control as compared to other examples; however, the inclusion of a supplemental heat source can also increase the complexity and overall cost of the system. Although FIG. **3** shows two supplemental heat sources **300***a* and **300***b*, it is contemplated that supplemental heat can be added to the fluid by use of only one supplemental heat source or multiple supplemental heat sources depending on the particular application. The supplemental heat sources **300***a* and/or **300***b* can be any form of supplemental heat source as would be appropriate for the particular application. For example, the supplemental heat sources **300***a* and/or **300***b* can be electrical resistive heating elements, propane burners, natural gas burners, solar thermal heating, or any other appropriate type of supplemental heat source for the application. The supplemental heat sources **300***a* and **300***b*, if both are installed in the system together, can be the same type of heat source or can be different types of heat sources. For example, supplemental heat source **300***a* can be a natural gas burner while supplemental heat source **300***b* can be an electrical resistive heating element.

In an example system, a supplemental heat source **300***a* can be positioned and configured to heat the fluid exiting the mixing valve **200**. For example, in response to determining that the temperature of the fluid exiting the mixing valve is less than the predetermined temperature setting, the controller **130** can output instructions to the supplemental heat source **300***a* to transfer heat to the fluid. As another example, the controller **130** can output instructions to the supplemental heat source **300***b* to transfer heat to the fluid exiting the heating chamber **101** and entering the mixing valve **200** in response to determining that the fluid exiting the heating chamber **101** is at a low temperature. As yet another example, the controller **130** can determine that the fluid temperature will fall below a predetermined temperature setting based on the current flow rate, current fluid temperature, and/or heat pump **120** capabilities, and in response to so determining, the controller **130** can output instructions to one or more supplemental heat source(s) **300***a*, **300***b* to transfer heat to the fluid. The predetermined temperature setting that is used to determine whether to engage or utilize the supplemental heat source(s) **300***a*, **300***b* can be the same or a different predetermined temperature setting that is used to determine whether to utilize the heat pump **120**. The supplemental heat source(s) **300***a*, **300***b* can be used in an on-demand heat pump water heater **100** whether or not the water heater **100** includes a mixing valve **200**.

Furthermore, it is contemplated that the supplemental heat source(s) **300***a*, **300***b* can be controlled by the controller **130** or by a separate controller (e.g., a controller dedicated to control of one or more supplemental heat source(s) **300***a*, **300***b*). If the supplemental heat source(s) **300***a*, **300***b* have a dedicated controller, the dedicated supplemental heat source controller can be in communication with the controller **130** or other components of the on-demand heat pump water heater **100**.

FIG. **4** is a logic diagram of an example on-demand heat pump water heater **100** system. FIG. **4** is not meant to limit the many different configurations in which the controller **130** can function but is given merely as an example for illustrative purposes. Furthermore, one of skill in the art will understand that the logic depicted in FIG. **4** can be altered as necessary to encompass the many different configurations of the on-demand heat pump water heater **100** as previously discussed or other configurations not discussed.

In an example, as shown in FIG. **4**, the controller **130** can perform a sequence of logic checks to operate the heat pump **120** and regulate the temperature of the fluid based on a predetermined temperature setting. In this example, the controller **130** can receive flow data from a flow sensor (e.g., flow sensor **106**) and determine **450** if the flow data indicates that fluid is flowing into the low fluid capacity heating chamber **101**. If the flow data indicates that fluid is not currently flowing, the controller **130** can send a control signal to the supplemental heat source (e.g., supplemental heat source **300***a* and/or **300***b*) to disengage **452**. The controller **130** can then receive temperature data from a temperature sensor (e.g., temperature sensor **108***a*, **108***b*, or **208***c*) and determine **454** if the temperature of the fluid in the low fluid capacity heating chamber **101** is below a predetermined temperature setting. If the temperature of the fluid in the low fluid capacity heating chamber **101** is below the predetermined temperature setting, the controller **130** can send a control signal to the heat pump **120** to engage **458** and begin heating the fluid. If the temperature of the fluid in the low fluid capacity heating chamber **101** is above the predetermined temperature setting, the controller **130** can send a control signal to the heat pump **120** to disengage **456** and cease heating the fluid.

If the controller **130** determines **450** that the fluid is currently flowing, the controller **130** can send a control signal to the heat pump **120** to engage **460** and begin heating the fluid in the low fluid capacity heating chamber **101**. The controller **130** can then receive temperature data from a temperature sensor (e.g., temperature sensor **108***a*, **108***b*, or **208***c*) installed near the fluid outlet **104** and determine **462** whether the fluid being delivered to the user is at a temperature that satisfies a predetermined temperature setting. If the temperature of the fluid near the fluid outlet **104** is below the predetermined temperature setting, the controller **130** can then send a control signal to a supplemental heat source (e.g., **300***a* and/or **300***b*) to engage **464** and begin adding supplementary heat to the fluid. On the other hand, if the temperature of the fluid near the fluid outlet **104** is above the predetermined temperature setting, the controller **130** can determine **466** whether the supplemental heat source (e.g., supplemental heat source **300***a* and/or **300***b*) is currently providing supplementary heat to the fluid. If the supplemental heat source (e.g. **300***a* and/or **300***b*) is currently providing supplementary heat to the fluid, the controller **130** can then send a control signal to the supplemental heat source (e.g. supplemental heat source **300***a* and/or **300***b*) to disengage **468** and cease providing supplementary heat to the fluid. If the supplemental heat source (e.g. supplemental heat source **300***a* and/or **300***b*) is not currently providing supplementary heat to the fluid, the controller **130** will take no action and begin the sequence over again by determining **450** whether flow sensor **106** detect fluid flow. This is merely one example of a method of controlling the on-demand heat pump water heater **100**, and one of skill in the art will understand that the controller **130** can be configured to control alternate configurations of the on-demand heat pump water heater **100** and the controller **130** can accordingly have multiple configurations functionalities as described herein. Furthermore, although this immediate example does not discuss use of a mixing valve **200**, one of skill in the art will understand that a mixing valve can be integrated into this and other examples.

While the present disclosure has been described in connection with a plurality of exemplary aspects, as illustrated in the various figures and discussed above, it is understood that other similar aspects can be used or modifications and additions can be made to the described aspects for performing the same function of the present disclosure without deviating therefrom. For example, in various aspects of the disclosure, methods and compositions were described according to aspects of the presently disclosed subject matter. But other equivalent methods or composition to these described aspects are also contemplated by the teachings herein. Therefore, the present disclosure should not be limited to any single aspect, but rather construed in breadth and scope in accordance with the appended claims.

What is claimed is:

1. A fluid heating device comprising:
- a fluid inlet;
- a fluid outlet;
- a heating chamber disposed in fluid communication between the fluid inlet and the fluid outlet, the heating chamber configured to hold a fluid and having a fluid capacity of approximately ten gallons or less;
- a heat pump configured to heat the fluid in the heating chamber;
- a controller configured to control a temperature of the fluid based on a predetermined temperature setting by controlling an output of the heat pump;
- a supplemental heat source disposed in fluid communication with the fluid outlet and configured to heat the fluid, wherein the controller is configured to control the supplemental heat source; and
- a fluid mixing valve in fluid communication with the supplemental heat source and the fluid inlet and configured to reduce the temperature of a fluid heated by the supplemental heat source.

2. The fluid heating device of claim **1**, wherein the fluid capacity is no more than 5 gallons.

3. The fluid heating device of claim **1**, wherein the fluid capacity is no more than 2 gallons.

4. The fluid heating device of claim **1** further comprising a temperature sensor configured to detect a temperature of the fluid.

5. The fluid heating device of claim **1**, further comprising a flow sensor configured to detect a flow of fluid downstream of the fluid inlet.

6. The fluid heating device of claim **1**, wherein the fluid mixing valve is controlled by the controller.

7. The fluid heating device of claim **1**, wherein the controller is a first controller, the fluid heating device further comprising a second controller configured to control the fluid mixing valve.

8. A method of controlling a fluid heating system, the method comprising:
- detecting, by a flow sensor, a flow of a fluid and outputting flow data;
- detecting, by a temperature sensor, a temperature of the fluid and outputting temperature data;
- in response to determining that the flow data indicates positive flow of the fluid, outputting, by a controller and to a heat pump, instructions to heat the fluid in a low fluid capacity heating chamber, the low fluid capacity heating chamber configured to hold a fluid and having a fluid capacity of approximately ten gallons or less;
- in response to determining that the temperature data indicates fluid temperature is less than a predetermined temperature setting, outputting, by the controller and to the heat pump, instructions to heat the fluid in the low fluid capacity heating chamber;
- outputting, by the controller and to a supplemental heat source disposed in fluid communication with a fluid outlet of the low fluid capacity heating chamber, instructions to heat fluid output from the low fluid capacity heating chamber; and
- outputting, by the controller and to a fluid mixing valve disposed in fluid communication with the supplemental heat source and a fluid inlet of the low fluid capacity heating chamber, instructions to reduce a temperature of a fluid heated by the supplemental heating source.

9. The method of claim **8**, further comprising:
- in response to determining that the fluid temperature cannot be maintained at a predetermined temperature setting for a predetermined amount of time based on the flow data and the temperature data, outputting, by the controller and to the heat pump, instructions to heat the fluid in the low fluid capacity heating chamber.

10. The method of claim **8**, further comprising:
- in response to determining that a fluid temperature is outside of a predetermined temperature range, output, by the controller, adjustment instructions to a fluid mixing valve.

11. The method of claim **8**, further comprising:
- in response to determining that the fluid temperature is less than a predetermined temperature setting, outputting, by a controller, instructions to a supplemental heat source to heat the fluid.

12. A system comprising:
- a low fluid capacity heating chamber configured to hold a fluid and having a fluid capacity of approximately ten gallons or less;
- a controller; and
- a memory having instructions stored thereon that, when executed by the controller, directs the controller to:
  - receive, at the controller and from a flow sensor, flow data indicative of a detected flow rate associated with the fluid;
  - receive, at the controller and from a temperature sensor, temperature data indicative of a detected temperature of the fluid;
  - in response to determining that (i) the flow data indicates a positive flow of the fluid or (ii) the temperature data indicates a fluid temperature that is less than a predetermined temperature setting, output a heat pump control signal to heat the fluid in the low fluid capacity heating chamber;
  - output, by the controller and to a supplemental heat source disposed in fluid communication with a fluid outlet of the low fluid capacity heating chamber, instructions to heat fluid output from the low fluid capacity heating chamber; and
  - output, by the controller and to a fluid mixing valve disposed in fluid communication with the supplemental heat source and a fluid inlet of the low fluid capacity heating chamber, instructions to reduce a temperature of a fluid heated by the supplemental heating source.

13. The system of claim **12**, wherein the heat pump control signal is a first heat pump control signal, and wherein the instructions, when executed by the controller, further direct the controller to:

output a second heat pump control signal by the controller in response to determining, based on the flow data and the temperature data, that a detected fluid temperature cannot be maintained by the system for a predetermined amount of time.

14. The system of claim **12**, wherein the instructions, when executed by the controller, further direct the controller to:

output a fluid mixing valve control signal by the controller in response to determining that the temperature data indicates a detected fluid temperature that is outside of a predetermined temperature range.

15. The fluid heating device of claim **5**, wherein the controller is further configured to: receive flow data from the flow sensor; and

in response to determining, based on the flow data, that the heat pump is unable to heat the fluid to a temperature greater than or equal to the predetermined temperature, output a control signal to the supplemental heat source to heat the fluid.

16. The fluid heating device of claim **1**, further comprising a condenser within the heating chamber.

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